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Passive Attenuating Communication Earphone (PACE): Noise Attenuation and Speech Intelligibility Performance When Worn in Conjunction with the HGU-56/P and HGU-55/P Flight Helmets

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Interim Report

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14. ABSTRACT
Noise attenuation and speech intelligibility measurements were conducted in accordance with American National Standards Institute (ANSI) S12.6 Methods for Measuring the Real-Ear Attenuation of Hearing Protectors and ANSI S3.2 Method for Measuring the Intelligibility of Speech over Communication Systems on the HGU-56/P and HGU-55/P flight helmets worn in conjunction with PACE in-the-ear, in-the-canal, and general purpose earplugs. The passive noise attenuation results for both helmets show an increase in attenuation across all frequencies from 125 to 8000 Hz with the PACE earplugs when compared to the helmet alone. Speech intelligibility results found average subject scores to be greater than 80% (necessary to meet air worthiness requirements) across all helmet configurations in the worst case noise condition.

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EXECUTIVE SUMMARY

The noise environment in the cockpit of military aircraft can be exceptionally loud at times. Flight helmets are required not only to protect the pilot from noise exposure, but also to provide communication capabilities. Passive communication earplugs were developed to improve both noise attenuation and communications under flight helmets. Warrior Edge designed the Passive Attenuating Communication Earphone (PACE) System that can be integrated with both the HGU-56/P and HGU-55/P flight helmets. The Air Force Research Laboratory's (AFRL) Battlespace Acoustics Branch collected noise attenuation and speech intelligibility data on the HGU-56/P and HGU-55/P flight helmets worn in conjunction with PACE in-the-ear (ITE), in-the-canal (ITC), and general purpose (GP) triple flange earplugs. Measurements were collected in accordance with American National Standards Institute (ANSI) S12.6 Methods for Measuring the Real-Ear Attenuation of Hearing Protectors[1] and ANSI S3.2 Method for Measuring the Intelligibility of Speech over Communication Systems.[2]

The results indicate that, for each helmet, the passive noise attenuation is greater at all frequencies from 125 to 8000 Hz with the PACE earplugs when compared to the helmet alone. Speech intelligibility for all helmet configurations was greater than 80% (necessary to meet air worthiness requirements) even in the worst-case noise condition. The attenuation data presented in this report are suitable for use in noise exposure calculations for the DoD and individual service hearing conservation programs. These data also meet the safe-to-fly checklist requirements for noise attenuation and speech intelligibility.

1.0 INTRODUCTION

Flight helmets are required in military aircraft for multiple reasons: ballistic/impact protection, reduce noise exposure, and provide communication capabilities. The HGU-56/P flight helmet was designed for rotor wing pilots and the HGU-55/P flight helmet was designed for fixed wing pilots (Figure 1). Passive earplugs (foam) were added to the helmet configuration in the operational community to reduce the level of noise at the ear; unfortunately the added attenuation made it difficult to understand speech. Communication earplugs were then developed to improve both speech intelligibility and noise attenuation. These devices may include custom fit or generic fit eartips, may be vented or non-vented systems, and varying shapes and materials. PACE earplugs were developed by Warrior Edge to improve pilot comfort, provide passive noise attenuation, and enhance communications. The low profile PACE ITE, ITC, and GP earplugs (Figure 2) are all vented to meet Air Force aircrew requirements. The ITE and ITC eartips are custom molded to personally fit each user. The ITE eartips fill the entire concha bowl of the external ear while the ITC eartips fill only the ear canal.

Figure 1. HGU-56/P (left) and HGU-55/P (right) flight helmets

Figure 2. PACE ITE (left), ITC (top right), and GP (bottom right) eartips

The purpose of this study was to integrate the HGU-56/P and HGU-55/P flight helmets with PACE to measure the noise attenuation and speech intelligibility of each configuration. The HGU-56/P helmets would use the already present communication port on helmets modified for Communication Earplugs (CEP). An adapter cable was created by Warrior Edge and directly link the helmet's communication port to the PACE cable (Figure 3). The HGU-55/P flight helmet was integrated using an adapter developed by Warrior Edge called the Y-Tap (Figure 4a). The Y-Tap allows PACE installation on the HGU-55/P helmet without changing any of the standard issue cabling or mounting to the oxygen mask (Figure 4b). It includes a volume potentiometer that allows PACE and the helmet to be used on all airframes regardless of the communication system installed. The Y-Tap allows a clean signal to pass through the earcup speakers with or without

PACE plugged in; the volume to the earcup is not affected by the Y-Tap volume potentiometer.

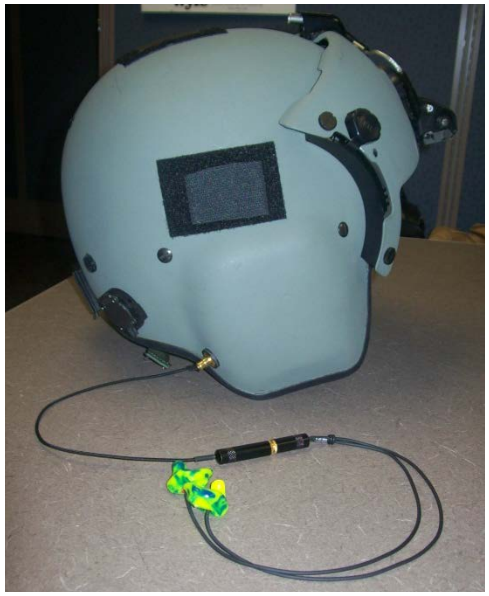
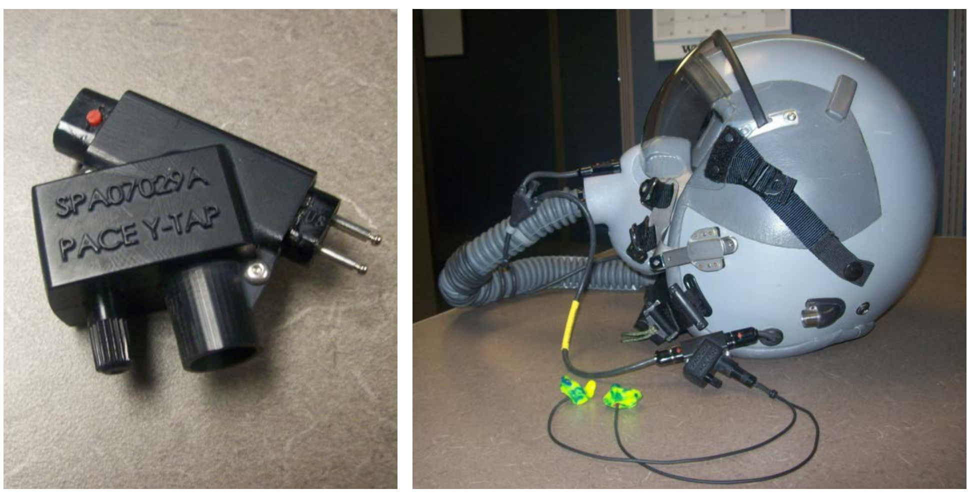


Figure 3. HGU-56/P flight helmet integrated with PACE



a. **b.**

Figure 4. a. Y-Tap b. HGU-55/P flight helmet integrated with PACE

2.0 METHODS

2.1 Subjects

Twenty paid volunteer subjects (9 male, 11 female) participated in the study measuring the noise attenuation performance of each of the helmet configurations. All subjects had hearing threshold levels less than or equal to 20 dB hearing level (HL) from 125 to 8000 Hz as determined by standard audiometric measures. The subjects ranged in age from 20 to 32 with a mean age of 25 years. Ear impressions were collected for each subject by a

trained technician and used to build the custom communication earplugs. A subset of 5 subjects participated in the speech intelligibility measurements (3 male, 2 female). These subjects had English as their native language and were trained to participate as both a talker and a listener.

2.2 Noise Attenuation

The AFRL Real Ear Attenuation at Threshold (REAT) facility was used to measure the passive attenuation performance of flight helmets worn in conjunction with communication earplugs. The chamber, its instrumentation, and measurement procedures were in accordance with ANSI S12.6-2008.[1] The procedures described in ANSI S12.6 consist of measuring the open ear (without the hearing protector) and occluded ear (with the hearing protector) hearing thresholds of human subjects (Figure 5) using a von Békésy tracking task. Psychoacoustic thresholds were measured two times for the open ear condition and two times for the occluded ear condition. The real-ear attenuation at threshold for each subject was computed at each octave frequency between 125 and 8000 Hz, by averaging the thresholds measured in the open and occluded ear conditions. The mean and standard deviation at each frequency was then calculated across subjects.

Figure 5. Subjects in REAT facility wearing the HGU-56/P flight helmet

Noise attenuation performance was measured for each flight helmet in conjunction with the PACE ITE, ITC, and GP earplugs as well as the HGU-56/P helmet alone (Table 1). Previous data on the HGU-55/P helmet were collected in 2001 and will be used in this report for comparison. Noise attenuation performance was also measured on the HGU-56/P helmet worn in conjunction with CEP earplugs. CEP are non-custom, foam ear tip, non-vented earplugs currently approved for flight with the HGU-56/P helmets. The Attenuating Custom Communications Earpiece System (ACCES) is already approved for flight with the HGU-55/P helmet. Noise attenuation data were collected in 2007 on this configuration and will be used for comparison.

Table 1. Test matrix for noise attenuation measurements

Experiment Number	Helmet		Earplug		
	HGU-56/P	HGU-55/P	PACE (ITE)	PACE (ITC)	PACE (GP)
1523	X		X		
1525	X			X	
1527	X				X
1528	X				
1522		X	X		
1524		X		X	
1526		X			X
1530	X		CEP, non-vented, non-custom		

2.3 Speech Intelligibility

The AFRL VOice Communication Research and Evaluation System (VOCRES) facility was used to measure the speech intelligibility performance of human subjects wearing the flight helmets worn in conjunction with communication earplugs. VOCRES was designed to evaluate voice communication effectiveness in operationally-realistic acoustic environments. The facility consists of a programmable, high-power sound system housed in a large reverberant chamber, capable of generating high-level (130 dB sound pressure level) noise emulating acoustic environments in operational situations. Ten operator workstations are positioned in the facility (Figure 6), each equipped with a touch-screen display and communication system capable of replicating end-to-end military communication chains (i.e., intercoms, oxygen systems, headsets, microphones, and helmets). In this way, full communication systems, as well as individual system components, may be evaluated under operationally-realistic conditions to determine the impact these systems might have on speech intelligibility and communication effectiveness.

Figure 6. AFRL's VOCRES facility used to measure speech intelligibility performance

Measurements were conducted in accordance with ANSI S3.2[2] with the exception of the number of subjects. A limited number of available helmets of various sizes reduced the number of subjects from 5 talkers and 5 listeners to 5 talkers and 4 listeners. The Modified Rhyme Test (MRT) was selected for the test material. Each subject speaks 50 word phrases as a "talker" and responds to 50 word phrases as a "listener." The list of target words was randomly ordered to form a unique talker phrase list for each subject. The talker's word list displayed the list of target phrases and was delivered in the following manner:

Number 1, you will mark **WENT** please.
Number 2, you will mark **HOLD** please.
Number 3, you will mark **PAT** please.
.
.
.
Number 48, you will mark **BUN** please.
Number 49, you will mark **SAG** please.
Number 50, you will mark **FUN** please.

Each talker completed 3 lists per noise level. The listener's list displayed a 6 word response ensemble in which the listener selected the correct target word. Below is an example response ensemble.

1.

Went	Sent	Bent
Dent	Tent	Rent

2.

Sold	Cold	Told
Fold	Hold	Gold

3.

Pan	Pad	Pat
Path	Pack	Pass

.
.
.

48.

Buff	Bus	But
Bug	Buck	Bun

49.

Sat	Sag	Sass
Sack	Sad	Sap

50.

Run	Sun	Bun
Gun	Fun	Nun

Measurements for the HGU-56/P helmet were collected in 65, 95, and 105 dB overall sound pressure level (OASPL). The measurements for the HGU-55/P helmet were collected in 65, 105, and 115 dB OASPL. The talker and listeners were in the same noise environment excluding one configuration of the HGU-56/P helmet, when the talker was seated in a separate room in 65 dB (Figure 7) and the listeners were in 105 dB.

Figure 7. Talker sitting in quiet environment completing speech intelligibility measurement with HGU-56/P helmet and PACE earplugs

Results were combined for all subjects per noise levels and helmet configuration. The subjects' scores were adjusted for guessing as described in ANSI S3.2 using the following formula.

$$R_A = \frac{R - W}{(n - 1)}$$

where R_A is the number of words correct adjusted for guessing/chance, R is the number of words correct, W is the number of words incorrect, and n is the number of alternative choices. An overall average was then calculated for all subjects.

3.0 RESULTS

3.1 Noise Attenuation

Passive noise attenuation data were collected in AFRL's REAT on multiple flight helmet configurations. Data were collected on the HGU-56/P alone and worn in conjunction with PACE ITE, ITC, and GP earplugs. The mean thresholds and standard deviation from 125 to 8000 Hz are listed in Table 2. The mean noise attenuation results are shown graphically in Figure 8. An increase in noise attenuation was measured at all frequencies when comparing the mean noise attenuation performance of the flight helmet with PACE to the attenuation of the helmet alone.

Table 2. Mean thresholds and standard deviation (dB) for the HGU-56/P flight helmet configurations

Helmet Configuration		Frequency (Hz)						
		125	250	500	1000	2000	4000	8000
HGU-56/P	Mean	7	8	13	27	34	37	39
	SD	6	6	5	4	6	7	8
HGU-56/P with PACE (ITE)	Mean	11	12	23	35	43	52	58
	SD	8	9	9	5	4	4	5
HGU-56/P with PACE (ITC)	Mean	13	15	27	36	44	52	56
	SD	8	9	9	6	4	4	6
HGU-56/P with PACE (GP)	Mean	14	14	24	33	42	52	53
	SD	10	10	10	5	4	6	9

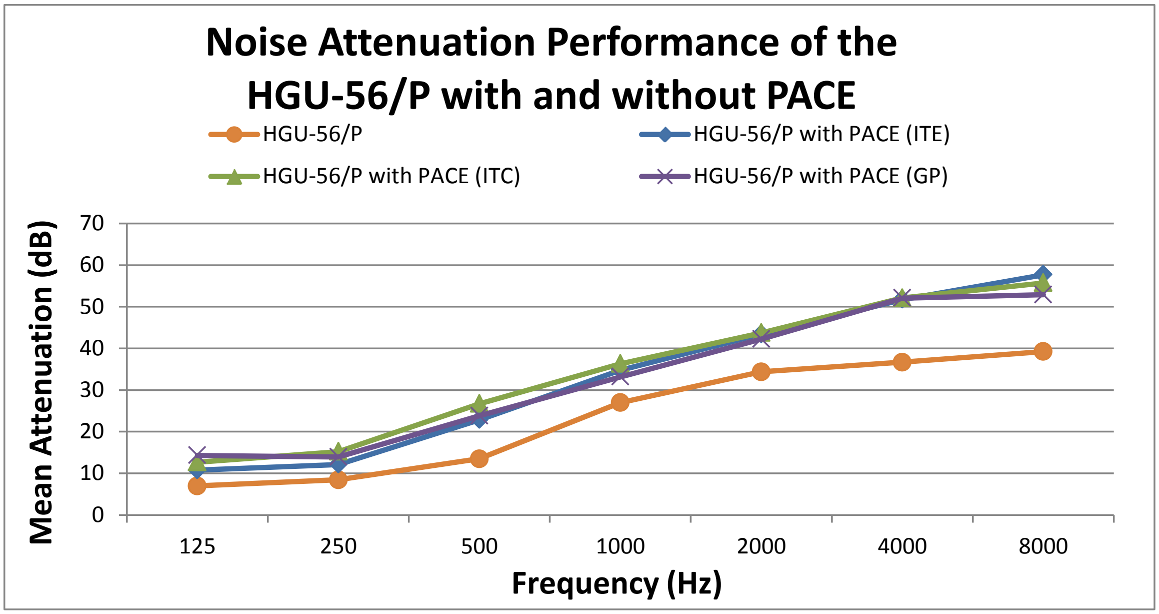


Figure 8. Mean noise attenuation results for the HGU-56/P flight helmet with and without PACE

Passive noise attenuation data were also collected on the HGU-55/P worn in conjunction with PACE ITE, ITC, and GP earplugs. The mean thresholds and standard deviation noise attenuation from 125 to 8000 Hz for all HGU-55/P helmet configurations are listed in Table 3. The mean noise attenuation results are shown graphically in Figure 9. An increase in mean noise attenuation was found at all frequencies when comparing the HGU-55/P with PACE earplugs to the HGU-55/P alone. Similar attenuation results were found when comparing the mean attenuation of the helmet with PACE to the previously collected mean attenuation of the helmet with ACCES.

Table 3. Mean thresholds and standard deviation (dB) for the HGU-55/P flight helmet configurations

Helmet Configuration		Frequency (Hz)						
		125	250	500	1000	2000	4000	8000
HGU-55/P (2001)	Mean	9	8	15	28	37	50	54
	SD	6	4	4	3	4	4	4
HGU-55/P with PACE (ITE)	Mean	15	15	26	37	47	56	61
	SD	8	7	7	7	4	4	4
HGU-55/P with PACE (ITC)	Mean	17	19	31	37	48	56	61
	SD	9	8	9	5	5	6	6
HGU-55/P with PACE (GP)	Mean	19	20	27	36	47	59	60
	SD	9	8	9	6	5	4	5

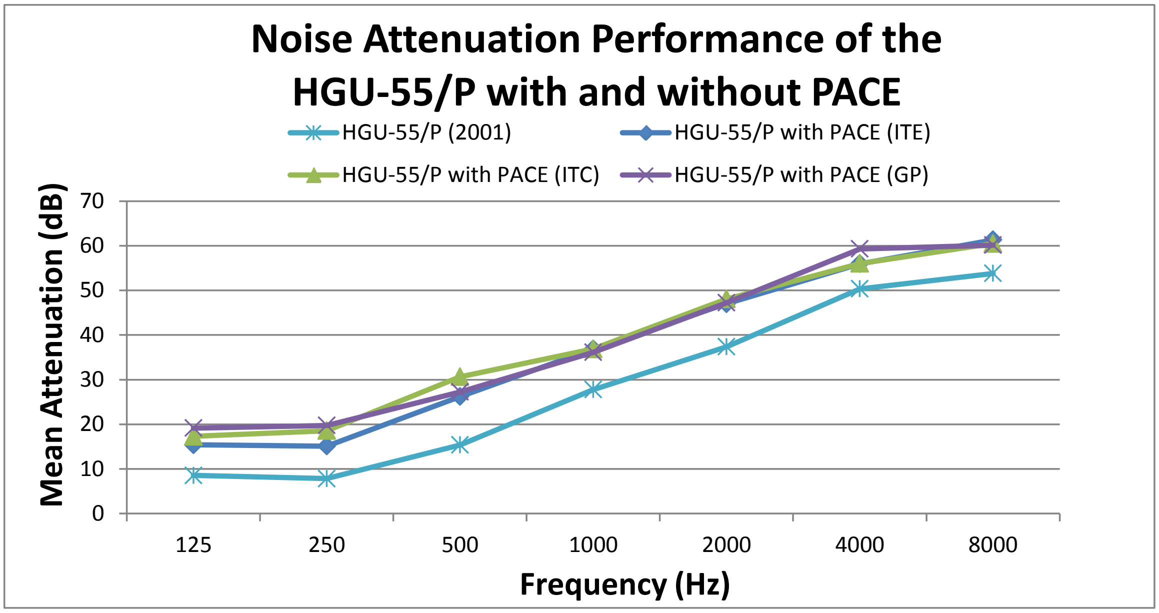


Figure 9. Mean noise attenuation results for the HGU-55/P flight helmet with and without PACE

3.2 Speech Intelligibility

Average speech intelligibility scores for all subjects were calculated per helmet configuration and noise level for the HGU-56/P (Table 4, Figure 10) and HGU-55/P (Table 5, Figure 11). As expected, intelligibility scores decreased as the ambient noise level increased. Although there were differences in the results, they were all within the acceptable range (< 80%) even in the worst case noise environment.

Table 4. Average speech intelligibility scores per HGU-56/P configuration and noise level

	HGU-56/P		
	PACE Earplug		
	Custom ITE	Custom ITC	Triple Flange GP
Noise Level	SI Score (%)		
65 dB	96.2	97.8	97.6
95 dB	89.3	92.1	92.0
105 dB	89.6	81.2	81.9

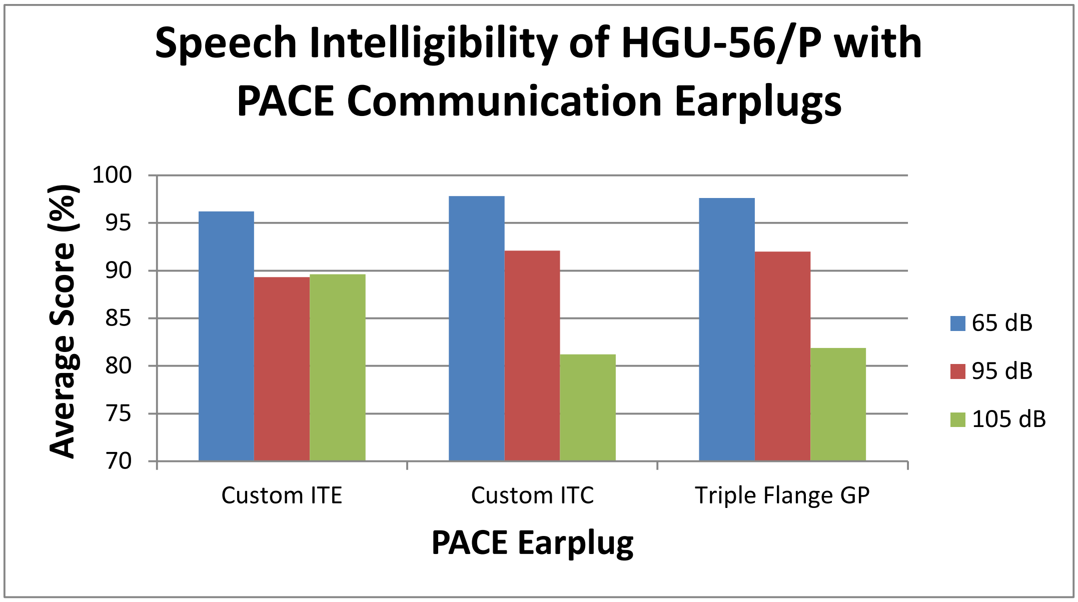


Figure 10. Average speech intelligibility scores for the HGU-56/P flight helmet with PACE

Table 5. Average speech intelligibility scores per HGU-55/P configuration and noise level

	HGU-55/P		
	PACE Earplug		
	Custom ITE	Custom ITC	Triple Flange GP
Noise Level	SI Score (%)		
65 dB	94.0	96.2	96.8
105 dB	89.6	94.2	94.0
115 dB	82.0	82.1	86.4

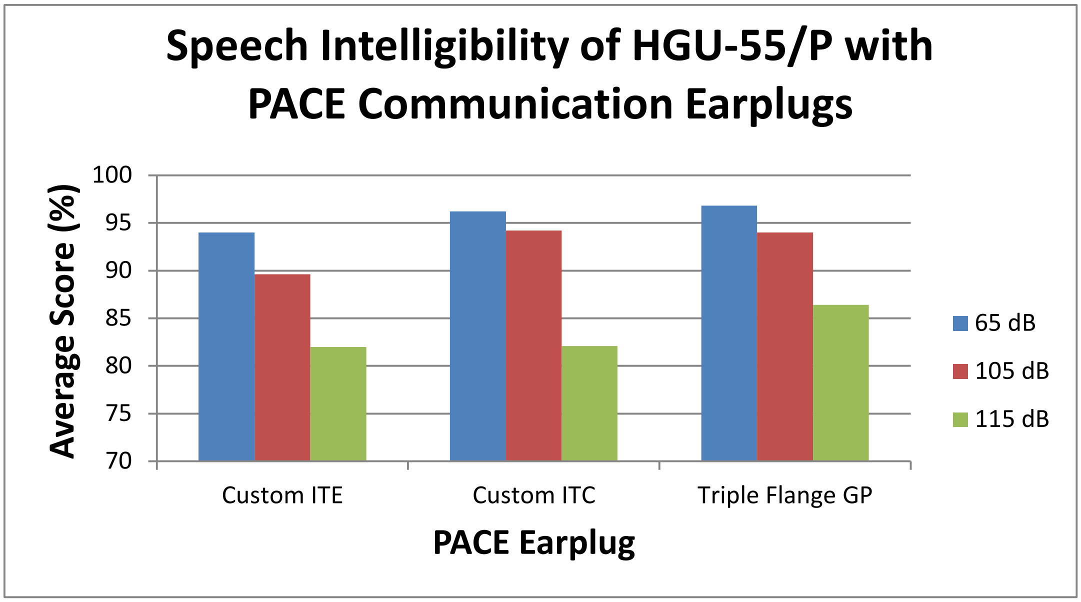


Figure 11. Average speech intelligibility scores for the HGU-55/P flight helmet with PACE

4.0 DISCUSSION

Passive noise attenuation data were collected on the HGU-56/P alone and worn in conjunction with PACE ITE, ITC, and GP earplugs as well as CEP (Figure 12). When comparing the HGU-56/P to the helmet noise attenuation requirement, the attenuation performance does not meet the requirement in the low frequencies (125-500 Hz). Rotor wing pilots are currently approved to wear CEP, a non-vented earplug, in conjunction with the flight helmet. PACE earplugs, however, were designed as a vented system to meet Air Force aircrew requirements; vented earplugs were developed to allow for pressure changes in the inner ear due to elevation changes. Unfortunately, the air vent introduces an acoustic leak. When comparing the noise attenuation results of the HGU-56/P with PACE and CEP (Figure 12), a difference is found in the low frequencies where the non-vented earplugs provide greater attenuation. This will always be the case when comparing a vented and non-vented system. Nonetheless, the passive noise attenuation of the HGU-56/P with PACE earplugs met or exceeded the helmet requirement at all frequencies except 125 Hz.

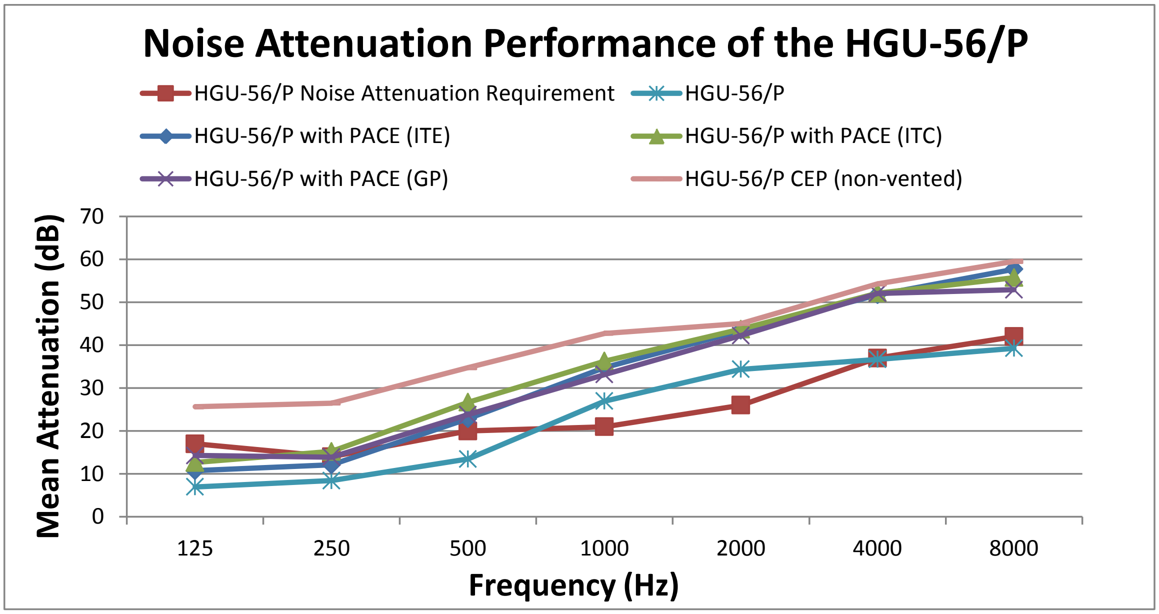


Figure 12. Mean passive noise attenuation performance of the HGU-56/P with communication earplugs and the helmet requirement

Fixed wing pilots are currently approved to wear ACCES in combination with the HGU-55/P flight helmet. Both systems are a vented design. Similar results were found when comparing the HGU-55/P flight helmet worn with PACE to that helmet with ACCES (Figure 13). No overall differences were found when comparing the mean noise attenuation results; however, the PACE earplugs do provide ear tip options (custom, material, shape) to accommodate personal preferences which may lead to greater operator acceptance.

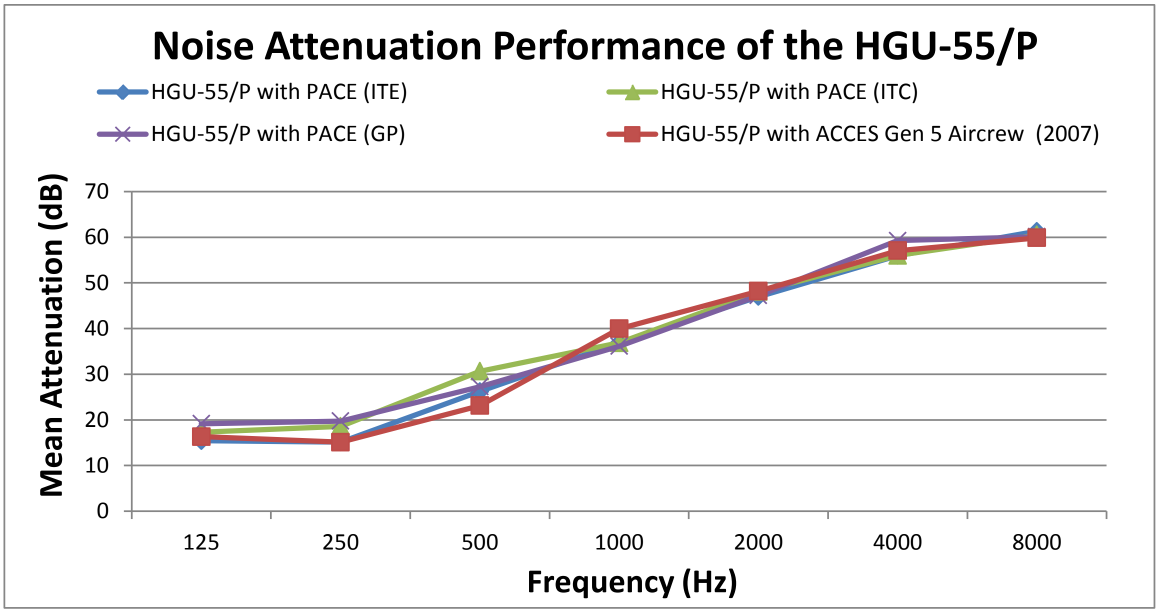


Figure 13. Mean passive noise attenuation performance of the HGU-55/P with communication earplugs

Speech intelligibility measurements were collected on the HGU-56/P and HGU-55/P helmets worn in combination with PACE ITE, ITC, and GP earplugs in a quiet, average, and "worst case" continuous noise environment. The average scores for all noise levels decreased when the noise in the lab increased, as expected. For a worst case noise condition, speech intelligibility scores must be greater than or equal to 80%. The flight helmets with PACE earplugs all scored greater than 80% for all test noise conditions.

A military cockpit can be a difficult noise environment in which to communicate. Communication signals are output directly into the ear of the wearer of communication earplugs from various sources: air traffic controllers, warning signals, AWACS, co-pilot and/or other crew members. An additional measurement was collected with the HGU-56/P helmet and PACE earplugs where the talker was placed in a 65 dB noise environment (more similar to controlling agencies, etc.) while the listeners remained in a 105 dB noise environment. The average scores increased greatly when compared to the test condition having the talker in the same noisy environment as the listener (Figure 14) where the listener would have to strain to understand the speech in noise. These results highlight the communication issues rotor wing pilots' face in the cockpit due to the poor input of the communication signal (boom microphone capturing speech and noise together).

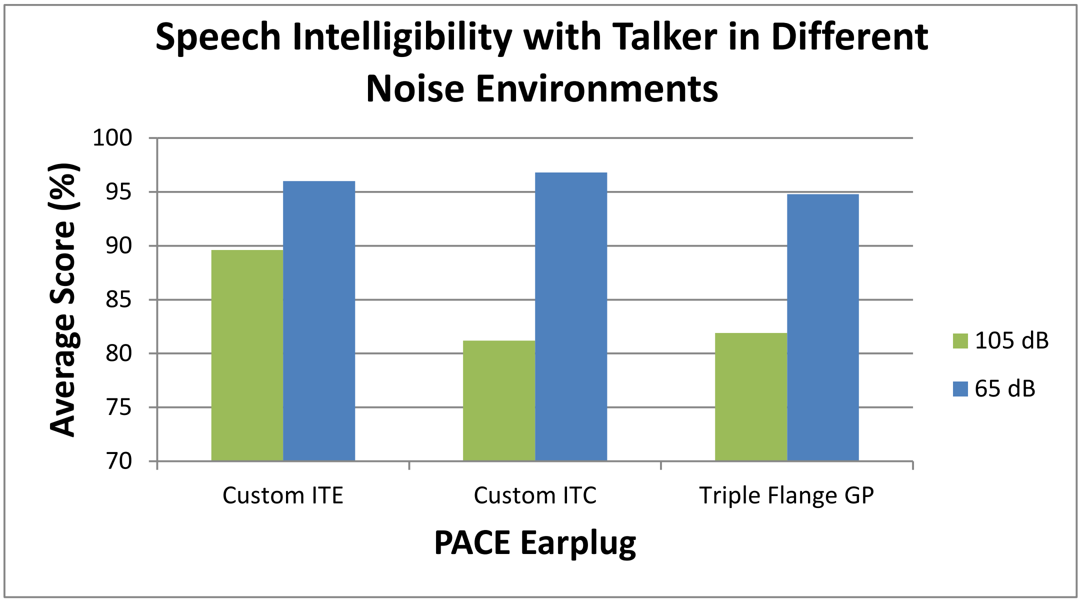


Figure 14. Average speech intelligibility scores for subjects wearing the HGU-56/P flight helmet with PACE comparing the results of the talker in 105 dB to the talker in 65 dB with the listener in 105 dB for each condition

5.0 CONCLUSIONS

Passive noise attenuation and speech intelligibility data were collected at AFRL in accordance with ANSI S12.6 and ANSI S3.2, respectively, on the HGU-56/P and HGU-55/P flight helmets worn in conjunction with PACE earplugs. The addition of communication earplugs to the flight helmet is crucial to adequately protect the rotor and fixed wing pilots from excessive noise exposure without degrading communications. The noise attenuation results for both helmets show an increase in attenuation across all frequencies from 125 to 8000 Hz with the PACE earplugs when compared to the helmets alone. The attenuation data presented in this report are suitable for use in noise exposure calculations for the DoD and individual service hearing conservation programs. Speech intelligibility results found average subject scores to be greater than 80% across all helmet configurations and noise levels.

6.0 REFERENCES

1. ANSI S12.6-2008 American National Standard Methods for Measuring the Real-Ear Attenuation of Hearing Protectors
2. ANSI S3.2-2009 American National Standard Method for Measuring the Intelligibility of Speech over Communication Systems